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INCREASING THE SERVICE LIFE OF COMPLEX STEEL CASTINGS

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ABSTRACT

The structural solution of such parts in terms of complexity and manufacturing material is diverse. The fittings are low-tech castings, in connection with this, it is necessary to clarify the power features of such cyastings. Austenitic chromium-nickel steel valves castings have stringent tightness requirements. The reason for the violation of the integrity of the castings during operation is most often captured (provided that the porosity does not receive excessive development). As a measure to combat captivity, the replacement of titanium with niobium should be recommended and pouring into dry sand forms. The valves design plays an important role in increasing the tightness. In order to provide directional solidification of castings, technological overlaps are widely used. The use of overlaps is most effective for castings of small and medium thickness. For massive castings, in the presence of overlays, the solidification time increases significantly, and they turn out to be less effective. Typically, a leak is found in the transition region of the casting wall to the flange at a distance of 5-50 mm from the flange. The study is based on direct thermal analysis of the solidification of complex castings. Thermocouples were installed in thermal centers. The thermocouples determined the duration of solidification of each of them. The gradient of the solidification duration determines the degree of directivity of the solidification and can be used for any casting at the design stage. Thus, the best direction of solidification is ensured when the metal is fed into the flange, and pouring should be carried out at 1530-1560^{0}C. The research results are the basis for the preparation of normals for cast steel valves. The implementation of this scheme in production recorded an improvement in the integrity of the casting. These recommendations are used in the manufacture of flange valves. When using the described scheme for flange valves, an increase in its tightness is recorded.

***KEYWORDS:** Steel Flange Valves, Directional Solidification Gradient, Valves Density and Reliability, Valve Tightness & Thermal Analysis of Solidification*

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Original Article

INTRODUCTION

Cast valves of various sizes made of chromium-nickel steels is widely used in power and chemical engineering. The fittings, as a part of a heavily loaded unit, play a crucial role, and the resource of continuous operation of the entire installation depends on its reliability.

The castings of austenitic chromium-nickel steel valves are subject to stringent tightness valves. Typically, a leak is found in the transition region of the casting wall to the flange at a distance of 5-50 mm from the flange.

An increase in the density of these nodes is ensured by technological methods, namely, by setting profit margins and rational way of supplying metal. The most rational is the attachment of profits to the surface of the flange.

Siphon filling of the casting is avoided to ensure density. The pouring temperature of steel 1X18H9T is usually taken to be 1570–16000^{0}C. The lifting speed of the metal is selected in the range of 30-40 mm/s [8].

Guiding materials, (GOST 32-569-2013 - flanged valves, decorated with walls to the flange) and the recommendations that designers use do not reflect complex cross-section power supply and obtaining them with minimal porosity. Thus, the value of the slope during the transition of the wall to the flange 1/5 for any ratios of the wall and flange thicknesses is indicated in the State Standards for ship and pipe fittings, and the slope length is not indicated at all.

The guidance technical materials of RTMN 23-65 (guiding technical materials for steel flange valves, nominal diameter ND100 GOST 8437-75) also indicate a slope of 1/5 and a length equal to the thickness of the flange. The use of a wedge transition is allowed only for critical castings. In other cases, it is recommended to arrange the transition from the wall to the flange with a fillet. However, studies have shown that with all kinds of fillet radii, the amount of shrinkage defects in the massive part of the junction of the two walls, when these recommendations are followed, remains significant. There is evidence that castings valves often lose their integrity during operation.

The most typical valve wall thicknesses are 10 and 20 mm. From the point of view of the likelihood of formation of defects in the form of oxide films, blockages, etc., a thinner wall is formed, undoubtedly, in less favorable conditions, especially its horizontal section.

METHODOLOGY

The study is based on direct thermal analysis of the solidification of complex castings. Thermocouples were installed in thermal centers. The thermocouples determined the duration of solidification of each of them. The gradient of the solidification duration determines the degree of directivity of the solidification and can be used for any casting at the design stage. The total volume of porosity, reduced as a result of the passage of the peritectic reaction, was also determined[5].

In general, a general porosity was formed, which determines the integrity of the casting. The use of samples in the form of plates determines the formation of the porous zone in a fairly accurate way [11].

RESULTS AND DISCUSSIONS

In order to study the development of defects during the formation of such a wall, L-shaped samples were cast that simulated the joint of a flange with a wall of 12-13 mm. Cast samples were heated for permeability testing.

The upper part was cut to half the thickness, then recesses along the casting axis was milled on both sides, so that the remaining thin part served as a permeability test site (Figure 1.).

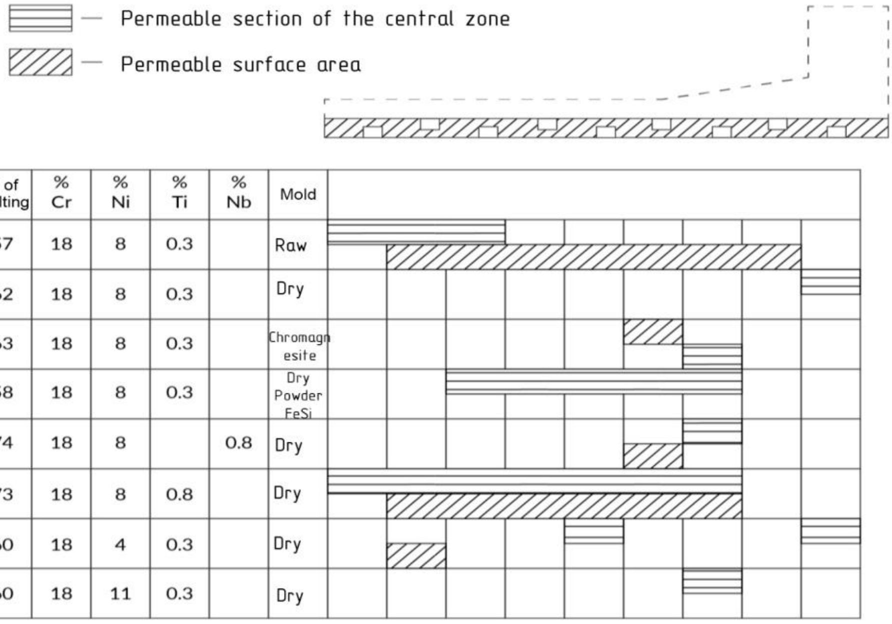


Figure 1: The Distribution of Permeable Areas for the Surface and Central Zones of a Thin Wall.

These test sites are formed in the central and surface casting zones. The presence of permeability of the test sites was noted by the shaded half of the cell (table. Figure 1). L-shaped samples were filled with steel with different nickel contents, as well as with the addition of titanium or niobium. Various conditions for the formation of the casting were created by measuring the state of the mold according to the following options:

- crude sandy clay;
- dry sandy clay;
- dry sandy clay with powder dust FeSi;
- drychromomagnesite on liquid glass.

The tests showed that the use of the crude form leads to the formation of a defective surface layer, the thickness of which can reach 2 mm. The permeability of this layer is due to the presence of captives and gas shells. Tests for the permeability of the surface zone directly below the film folds showed that a leak is detected when the thickness of the test wall is less than 1.4 mm.

When casting in a dry mold, especially with FeSi dust, the permeable surface layer in the casting is eliminated. The use of a chromomagnesite mixture having high thermal activity leads to some deterioration in the state of the surface layer.

In steel with 4% nickel, a permeable surface layer is observed, an increase in nickel to 11% leads to a decrease in these defects, since nickel reduces the tendency to foam formation [7].

An increase in the titanium content to 0.7–0.8% greatly increases the formation of surface defects [8]. Replacing titanium with niobium significantly improves the condition of the surface layers of the casting.

A test of the permeability of the central part of the horizontal wall showed that shrink or gas shrink pores are always present in it to a greater or lesser extent. This zone of axial porosity can reach 2-3 mm in thickness. The degree of

its development is determined by the composition of the steel [1].

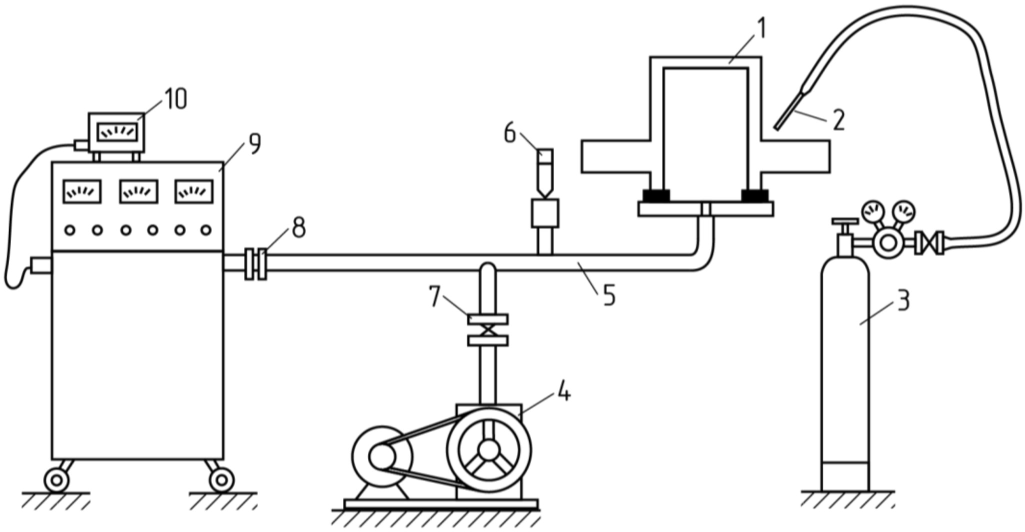
Studying the tightness of castings was carried out on a special casting-sample. Its design imitated the casting of flanged valves. The sample has a thin wall and a thick flange; the transition between them was decorated with a fillet. The sample had a chamber open on one side, which is convenient for conducting a leak test. The casting was fed during the hardening process in such a way as to create the possibility of the formation of shrinkage defect [8] in the flange-wall assembly.

To check the tightness of the experimental castings, the helium jet method was used (Figure 2).

For this, the internal cavity of the casting was connected to a vacuum system from which air was pumped out. From the side of the outer surface, the casting was blown with a thin stream of helium. In the presence of a through pore in the casting, a certain amount of helium fell into the internal cavity of the casting, then into the vacuum system, where a leak detector detected it.

In order to study the technological conditions for the production of castings to maintain tightness, during operation, the tested castings for tightness were subjected to alternating loads.

In accordance with the operating conditions of some types of valves, the cyclicity of the load was created due to the cyclically changing temperature "heating-cooling". The casting is heated using high frequency currents to a temperature of the order of 600-700^{0}C, and cooling is performed in air, and then in water. Such heating and cooling was repeated a certain number of times. The duration of each cycle was 7-8 minutes.



1 - Experimental Casting; 2 - a Tube for Blowing; 3 - Cylinder with Helium; 4 - Vacuum Pump; 5 - Pipeline; 6 - Pressure Gauge; 7 - Check Valve; 8 - Valve; 9, 10 - Measuring Equipment.
Figure 2: Installation Diagram for Testing Castings for Leaks.

The study of the complex effect of casting technology and metal composition on the integrity of castings simulating reinforcement was carried out on experimental castings. According to the conditions indicated in Table 1, experimental castings were obtained and their tightness was checked using a gel leak detector. To study the preservation of the integrity of the castings during operation, they were subjected to cyclically changing temperatures, respectively causing

alternating sign voltages.

After the first 30 cycles of “thermal pumping”, the experimental castings of the first batch were tested for leaks. A leak was recorded in a cast in a wet mold. A leak was found on the cylindrical surface of the casting and corresponded to a large film fold. After the next 30 cycles of “thermal pumping”, the leakage values increased significantly. Castings poured into a dry form did not have film folds on their surface and remained airtight after 30 cycles of “thermal pumping”.

The second batch of castings was poured into dry forms, with a variable composition of steel (Table 1). After the first 30 cycles of “thermal pumping", no leaks were found in the studied castings. After the next 30 cycles of “thermal pumping”, a leak was detected in a casting made of steel with high titanium content. On the surface of this casting, no ordinary pleated folds were detected, although in all likelihood there were captures in the body of the casting.

Table 1: The Test Results for the Tightness of Experimental Castings after Cyclic Loading

Number of casting	The composition of the steel, (%)					Casting Conditions	Leak test after "thermal pump"		
	Cr	Ni	C	Ni	Nb		30 cycles	60 cycles	120 cycles
57	18,0	7,8	0,06	0,3	-	Rawform	Weakleak	Strongleak	-
58	20,0	8,0	0,06	0,3	-	Dryformwithdust	No	No	No
59	20,8	8,0	0,06	0,3	-	Dry form with low pour temperature	No	No	-
60	19,8	4,2	0,06	0,3	-	Dryform	No	No	-
62	19,7	8,0	0,06	0,3	-	-	No	No	No
63	19,7	7,9	0,06	0,3	-	Chromiumform	No	No	-
73	18	8	0,06	0,8	-	Dryform	No	Leak	-
74	18	8	0,06	-	0,8	-	No	No	-
75	18	11	0,06	0,3	-	-	No	No	-
78	18	8	0,1	0,3	-	-	No	No	-

Experimental castings made of steel with 8% nickel retained their tightness (other than those specifically indicated) after thermal pumping in 60 and 120 cycles, despite its greater tendency to develop shrinkage porosity than steel with 4 or 11% nickel.

Thus, it should be assumed that the cause of the leakage of castings during operation is most often captured (provided that the porosity does not receive excessive development).

As a measure to combat captivity, the replacement of titanium with niobium should be recommended and pouring into dry sand forms.

In increasing the tightness, the valves themselves play an important role. In order to provide directional solidification of castings, technological overlaps are widely used. The use of overlaps is most effective for castings of small and medium thickness. For massive castings, in the presence of overlays, the solidification time increases significantly, and they turn out to be less effective.

As production experience has shown, the design of the transition from the flange to the wall is especially important for flange valves. In order to study in detail the formation of the transition node from the wall to the flange, castings-samples simulating this transition were poured (Figure 3). In such castings, the thickness of the vertical part changed, imitating the flange ($\boldsymbol{\delta}_{ф}$), the length of the wedge part ($\iota_{укл}$) and the slope value. A sample width of 100 mm was selected to exclude the effect of lateral cooling. The length of the sample 250 mm was chosen similar to the length of the

fed nodes of the valves.

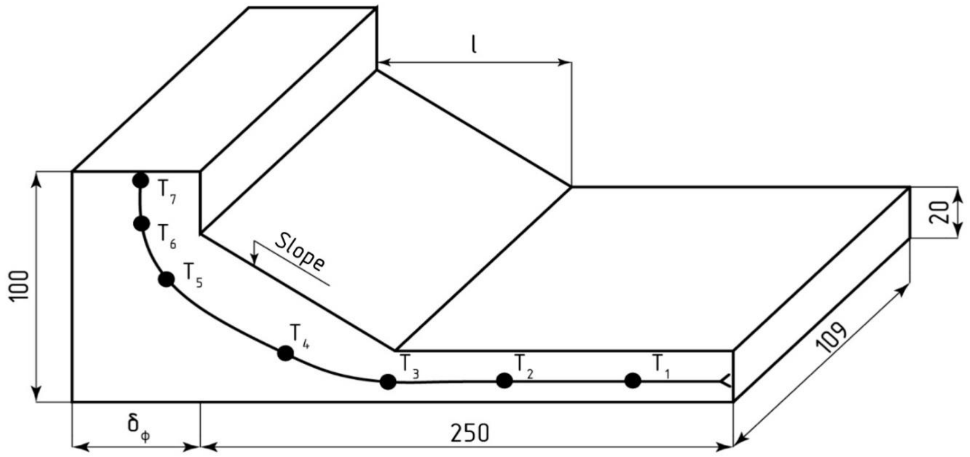


Figure 3: Type of L-Shaped Sample without Profit: T1 ÷ T7– Installation Points of Thermocouples.

The flange thicknesses of 80, 70, 60 and 50 mm are selected as typical for valves.

Table 2: The Dimensions of the Transition from the Horizontal Thin Wall to the Flange Were Selected on the Basis of the Recommended by Gost Rtma-1/5 and with a Deviation to the Larger and Smaller Side

Slope				
1/3	1/5	1/10	1/15	0
Wedge length in mm				
100	75	50		0

All castings were flooded at a temperature of 1530^{0}C (overheating 900). Profits were installed directly on top of the flange. The metal was supplied to the profitable part of the sample.

The study of heat sink, which determines the directional solidification of the casting, was studied by thermal analysis. For this, thermocouples were installed in the mold cavity at points T1 ÷ T7 (Figure 3).

The temperature curves (Figure 4) obtained for certain points of the experimental casting were processed in such a way as to obtain a change in the solidification time along the length of the casting (Figure 5). According to the obtained curve, an increase in the solidification time is traced in the direction from the end to the neck of profit. A certain degree of increase in the duration of solidification provides the direction of solidification.

However, the distribution of the solidification time does not fully reflect the nutrition process, since the formation of porosity ends until it hardens completely. By comparing the distribution curves for the temperature reaching half and three quarters of the crystallization interval, we can verify their complete similarity (Figure 5).

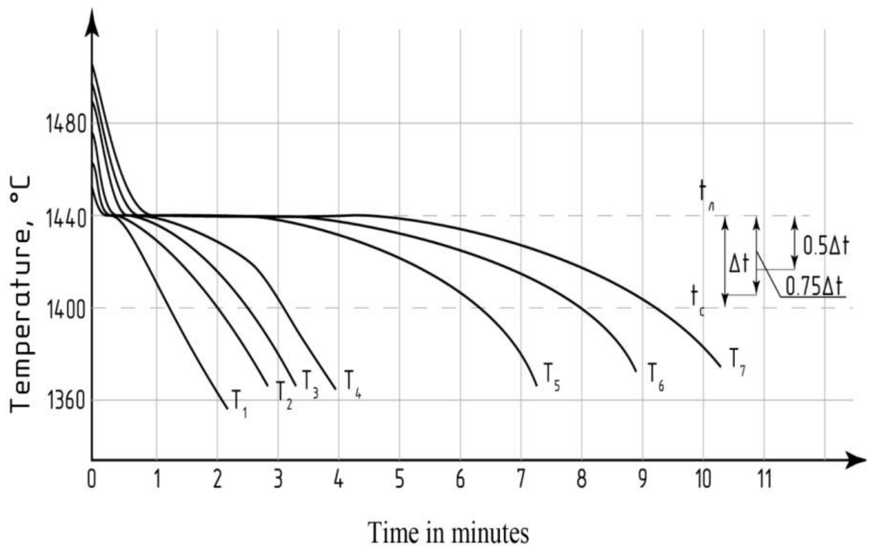


Figure 4: L-Shaped Solidification Curves.

We consider only the distribution curves of complete solidification.

Analyzing the curves of changes in the solidification time for castings with different thicknesses of the flange, the slopes and the length of the wedge part (Figure 5-8), we observe that with relatively small changes in the nature of these curves, a significant change in the density of individual sections takes place. The presence of small horizontal areas on the curves of changes in the solidification time corresponds to the minimum density values.

For a more convenient analysis of the curves of the distribution of solidification time, the slope of each section of the curve changed, the value of which Δτ/Δl was plotted on a separate graph (Figure 6). This characteristic, called the time gradient, gives a clear idea of the solidification conditions of the casting.

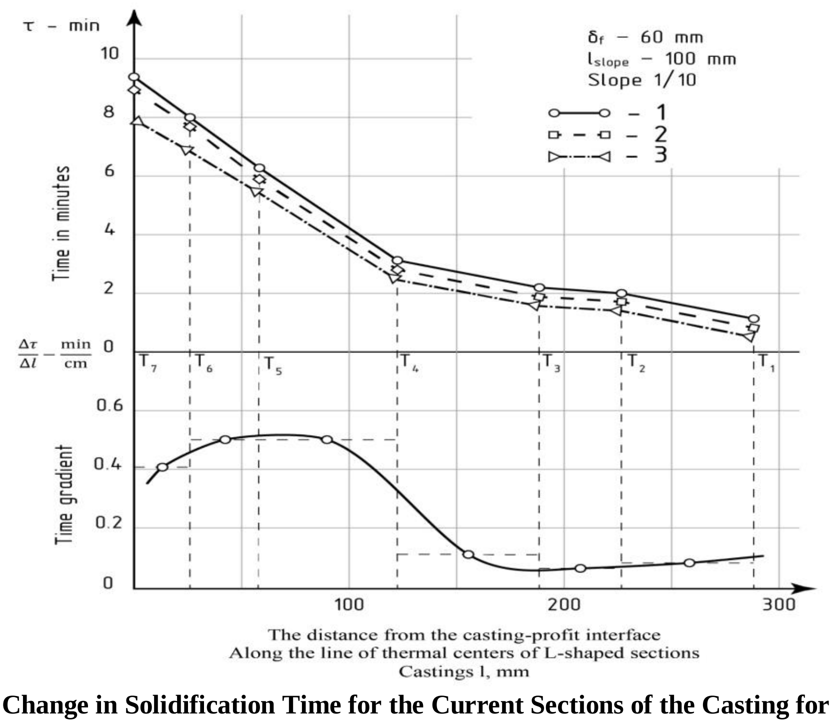


Figure 5: Change in Solidification Time for the Current Sections of the Casting for Complete Solidification (1); for ¾ Interval (2); for ½ Interval (3). Scheme for Constructing a Temporary Solidification Gradient

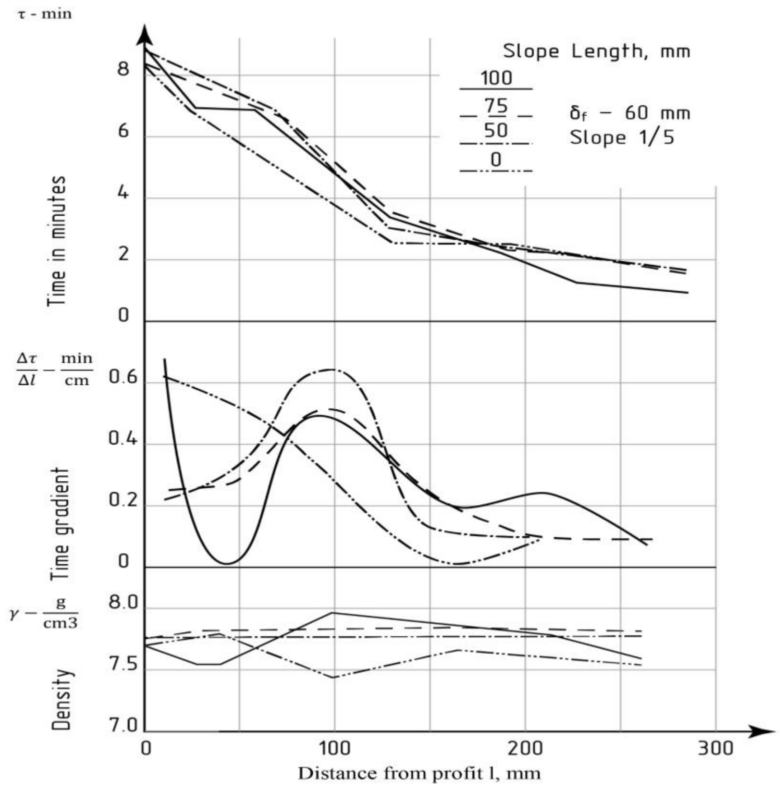


Figure 6: Change in the Solidification Time τ and the Time Gradient along the Length of L-Shaped Samples Having a Vertical Wall Thickness of 50 mm, a Wedge Transition Length of 100 mm and a Different Slope of 1:10; 1: 5; 1: 3.

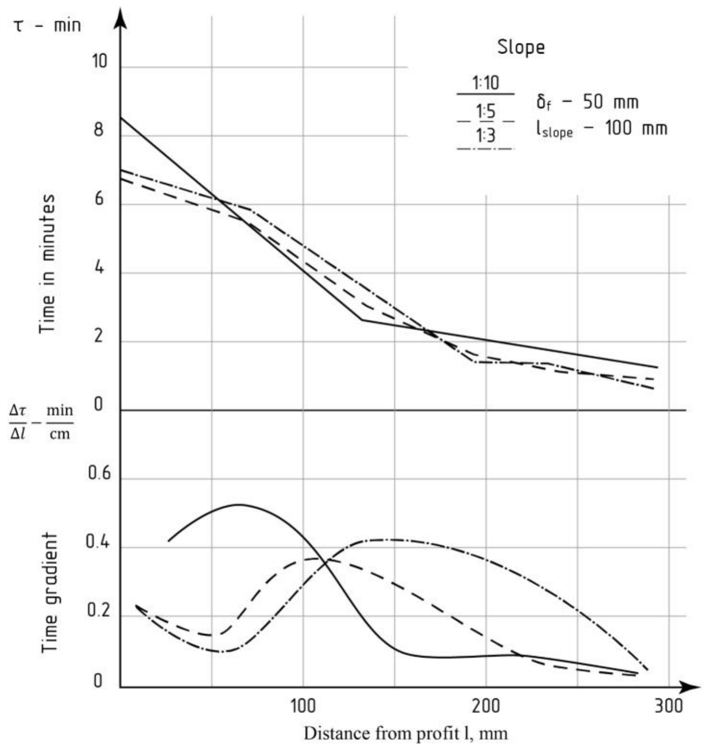


Figure 7: Change in the Solidification Time τ and the Time Gradient along the Length of L-Shaped Samples Having a Vertical Wall Thickness of 50 mm, a Wedge Transition Length of 100 mm and a Different Slope of 1:10; 1: 5; 1: 3.

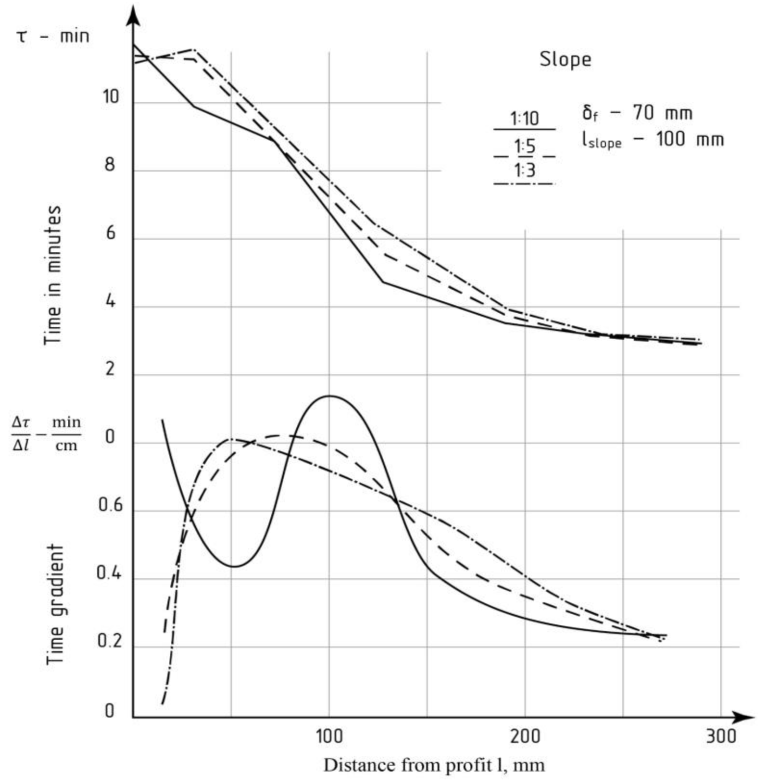


Figure 8: Change in the Solidification Time τ and the Time Gradient along the Length of L-Shaped Samples Having a Vertical Wall Thickness of 70 mm, a Wedge Transition Length of 100 mm and a Different Slope of 1:10; 1: 5; 1: 3

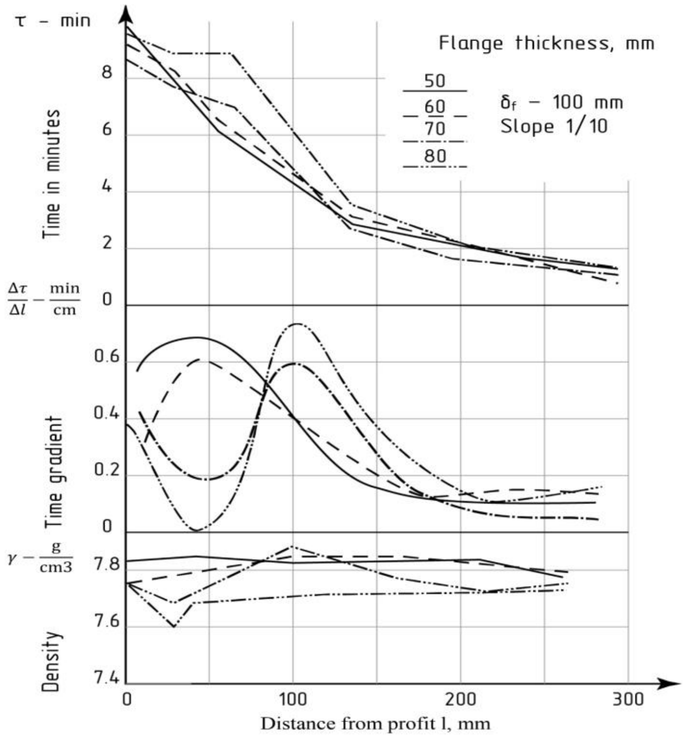


Figure 9: Change in the Solidification Time τ and the Time Gradient along the Length of L-Shaped Samples Having a Wedge Transition Length of 100 mm, a Slope of 1:10 and Various Vertical Wall Thicknesses of 50, 60, 70, 80 mm.

A similar character of its change Δτ/Δl with the density distribution in the casting is observed, in particular, the minimum value of the density corresponds to the minimum of the temporary gradient, however, a sharp increase in the gradient does not lead to an increase in density above a certain value [9].

For most curves of the distribution of the temporal gradient, there is a slight increase from the end of the casting and a sharp increase at the beginning of the wedge transition. At this point, a drop in density is never observed. At the site of the junction of the wall and flange, the value of the temporal gradient has a minimum, the absolute value of which changes when the dimensions of the structural elements of the transition change.

For castings with a small slope of 1/15 or without it, a minimum Δτ/Δl is observed in the horizontal wall, which is caused by a decrease in the profit influence zone. At the same time, for casting without a wedge transition, there is no minimum Δτ/Δl corresponding to the transition node, which indicates a high degree of directivity of solidification of this section [10].

Thus, the task of finding the best structural design of the transition from the wall to the flange is to solve the complex problem of simultaneously ensuring in the casting a sufficient degree of directivity of the solidification of the horizontal wall of the junction.

If we use the value of the time gradient as a criterion for assessing the direction of solidification, then it turns out that in the end part of the casting, the Δτ/Δl value of 0.05 min/cm is sufficient to obtain a density of the order of 7.75 g/cm^3; this value of the gradient in the flange part corresponds to its lower value.

According to the study of the solidification of L-shaped castings (Figure 9), it is easy to see that a minimum of a temporary gradient of 0.19 min/cm corresponds to a decrease in density to 7.7 g/cm^3. In the previously considered cases, at values of more than 0.21 min/cm, a decrease in density below 7.75 g/cm^3 is not observed at the junction of the L-shaped casting. This section hardens in approximately 7 minutes. In thinner sections, hardening in about 1.5 minutes, to ensure a density of 7.75 g/cm^3, it is sufficient to have a value of a temporary gradient of at least 0.05 min/cm. Thus, in order to ensure the density, a certain correspondence must be fulfilled between the solidification time and the time gradient in a given section of the casting (Figure 10).

This dependence can be used to select the solidification conditions of castings.

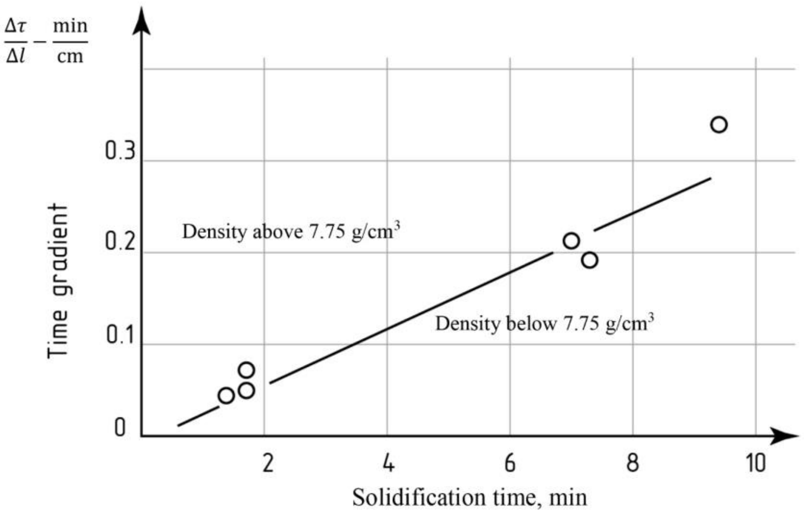


Figure 10: Change in the Minimum Time Gradient Necessary to Ensure the Density of Steel 7.75 g/cm^3, Depending on the Duration of Solidification of this Section.

Based on this dependence, the data of thermographic studies of L-shaped castings were analyzed and satisfactory design options marked with a (+) sign and unsatisfactory ones marked with a (-) sign in Table 1.3 were determined.

From these results, it follows that with a wall thickness of 20 mm, flange thicknesses of 50 and 60 mm are most suitable; the slope is 1/10 when the length of the wedge is 100 mm; or the slope is 1/5 when the length of the wedge is 50 or 75 mm.

A small slope of 0 and 1/15 does not provide sufficient power for the thin wall at any thickness of the flange (zone 1). The junction of the flange and the wall in this case has good power conditions.

With large slopes of the wedge part and flange thicknesses, the opposite is observed. Horizontal - it eats well from profit, and in the zone of articulation of the flange and wall, a thermal unit forms and porosity develops (zone 2). Small flange thicknesses with medium slopes of the wedge part provide power to the wall and wall joints with the flange (zone 3). In this case, excessive massiveness of the specified joint is not created.

It is more convenient to evaluate the massiveness of the transition by the height of the wedge part than by the ratio of its length and the slope value. From the values of the height of the wedge transition given in Table 1.4, it can be seen that the nutritional conditions for L-shaped samples are fulfilled in a relatively narrow range of variation of this value. Thus, with a height of the wedge transition of 10-15 mm and a length of 50-100 mm, favorable nutritional conditions for this type of sections are provided, with a wall thickness of 20 mm. Testing the axial zone by gas purging showed complete agreement between permeability and density. Permeability is absent at a density of 7.9 g/cm^3.

In the general case, we can conclude that the best ratio of flange thickness d_f and d_{wall} is d_f/d_{wall} = 2.5–3.0 mm. The best slope value is 1:10 when the ratio of the length of the wedge part to the wall thickness is $5 \cdot d_{wall}$, and when the length of the wedge part is 2.5-3.8 d_{wall}, the best slope is 1: 5.

The influence of the pouring temperature is shown by the curves in Figure 11. Comparing the nature of the change in the temporal gradient for samples poured at temperatures of 1560, 1530, and 1500^{0}C, one can notice that the change in $\Delta\tau/\Delta l$ for a sample poured at a temperature of 1530^{0}C has a more favorable form. When the solidification time is up to 2 min, the $\Delta\tau/\Delta l$ value does not decrease below 0.1 min/cm and then increases, exceeding 0.21 min/cm, which is a guarantee of obtaining a metal with a density below 7.75 g/cm^3.

Table 3: The Results of the Action of Various Wedge Parts

Slope	The Length of the Wedge, mm	Flange Thickness, mm			
		50	60	70	80
0	0		-		
1/15	100		-	1	
1/10	100	+	+	-	-
1/5	50	3	+		
1/5	75		+	2	
1/5	100	-	-	-	
1/3	100	-	-	-	

L-shaped samples having favorable (+) and unfavorable (-) nutritional conditions, depending on the structural dimensions:

- the section of the flange and the wall has good nutrition;
- the wall of the casting has good nutrition;

- the joint and wall of the casting are well nourished

Table 4: The Maximum Height of the Wedge Transition of the L-Shaped Sample, Depending on the Length of the Wedge Part and the Slope

Slope	The length of the wedge, mm		
	50	75	100
	Wedge height, mm		
1/15	3,3(1)	5,0	6,6
1/10	5,0	7,5	10,0
1/5	10,0(3)	15,0	20,0
1/3	16,7	25,0	33,3

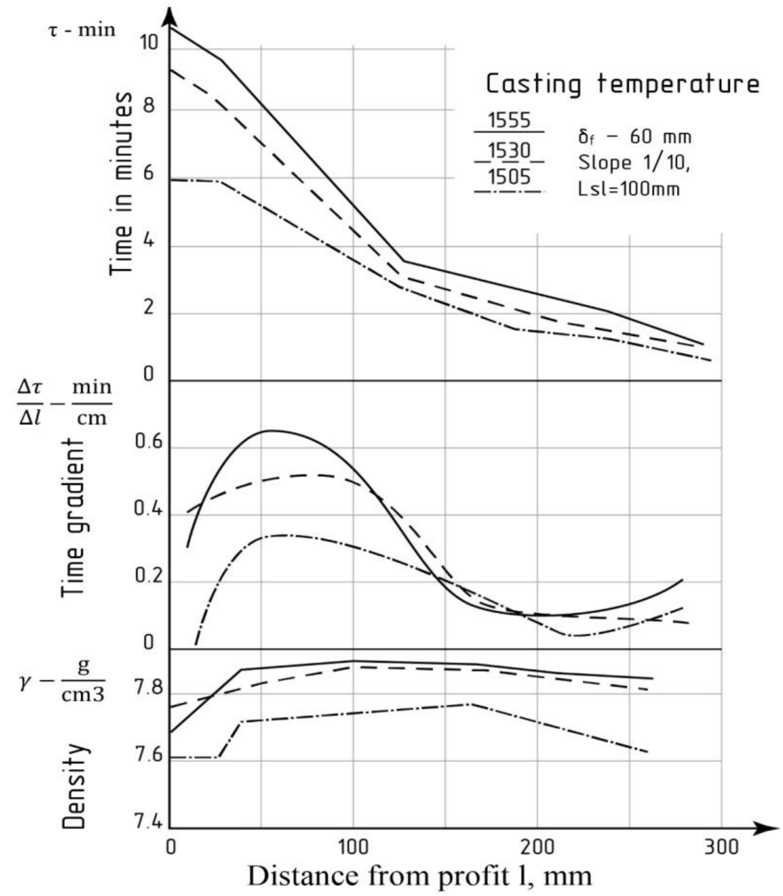


Figure 11: Change in Solidification Time τ, Time Gradient and Density γ along the Length of L-Shaped Samples Having a Vertical Wall Thickness of 60 mm, a Wedge Transition Length of 100 mm, a Slope of 1:10 at Various Pouring Temperatures of 1555, 1530 and 1505^{0}C.

The low pouring temperature worsens the impregnation of the horizontal part of the sample, slightly heats the sub-profitable part, and thereby lowers the temporal gradients along the entire length of the casting [13]. The increased pouring temperature greatly warms up the metal supply region, which causes a local increase in gradients in the region of the junction, but at the same time the gradients in the sub profit and horizontal parts of the sample decrease slightly [6].

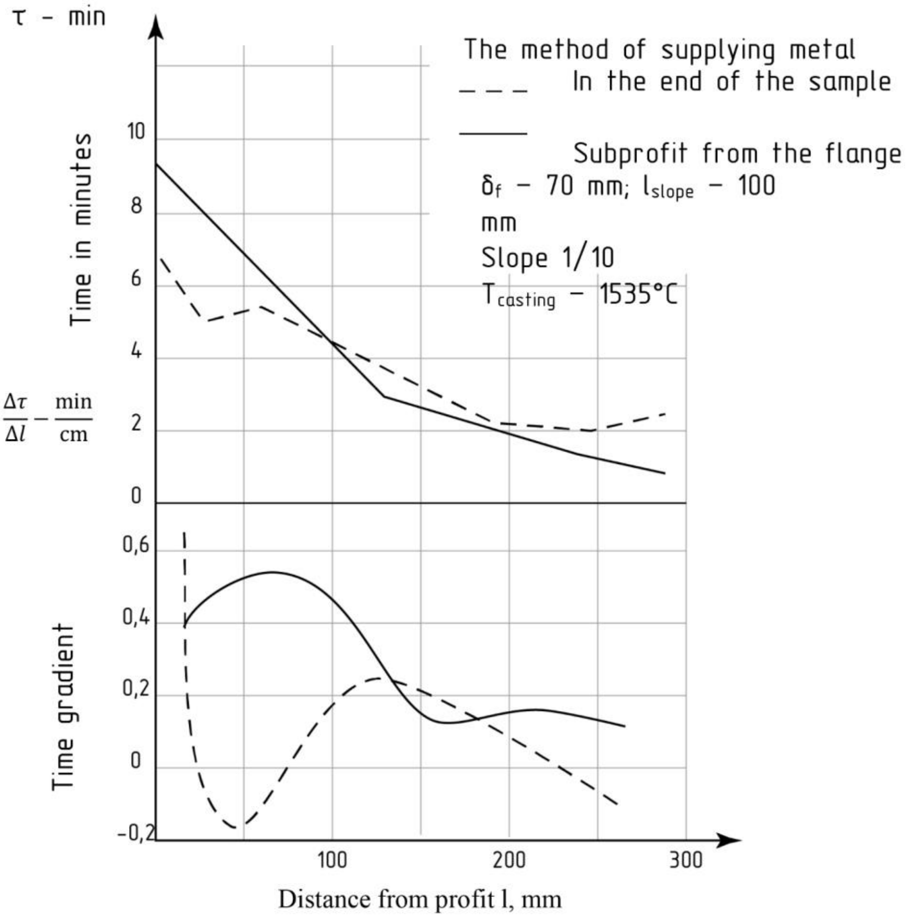


Figure 12: Change in the Solidification Time τ and the Time Gradient along the Length of L-Shaped Samples with Two Metal Supply Options Having a Vertical Wall Thickness of 60 mm, a Wedge Transition Length of 100 mm, a Slope of 1:10, and a Casting Temperature of 1535°C.

The study of the influence of the method of supplying metal into the mold (Figure 12) revealed that the supply of metal through the end of the sample leads to local negative time gradients [1]. Negative $\Delta\tau/\Delta l$ values are observed near the ends and at the junction of the flanges and the wall. The decreases $\Delta\tau/\Delta l$ are so significant that one should expect large shrinkage defects in the indicated sections [10,12].

CONCLUSIONS

- In the process of technology development, the casting is conditionally divided into volume elements.
- The duration of solidification is determined for each element.
- The value of the duration of solidification is consciously selected so that each subsequent element in the direction of profit hardens longer by the value of the time gradient. In general, directional solidification and a dense structure of the casting are formed.
- This design is recommended for any casting[2].

Thus, the best direction of solidification is ensured when the metal is fed into the flange, and pouring should be carried out at 1530-1560^{0}C.

The results of the study are the basis for the preparation of normals for steel cast valves. The implementation of this scheme in production recorded an improvement in the integrity of the casting. These recommendations are used in the manufacture of flanged valves[3, 4].

When using the described scheme for flange valves, an increase in its tightness was recorded [14].

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